

A novel modified mountain gazelle optimizer for tuning parameter proportional integral derivative of DC motor

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ABSTRACT

This article presents a modified method of mountain gazelle optimizer (MMGO) as a direct current (DC) motor control. Mountain gazelle optimizer (MGO) is an algorithm inspired by the life of the mountain gazelle animal in nature. This animal concept has five essential steps that are duplicated in mathematical modeling. This article uses two tests to get the performance of the MMGO method. The first test uses a benchmark function test with a comparison method, namely the sine tree seed algorithm (STSA) and the original MGO. The second test is the application of MMGO as a DC motor control. The simulation results show that MMGO can reduce the overshoot of conventional proportional integral derivative (PID) control by 0.447% and has a better integral time square error (ITSE) value of 5.345 than conventional PID control. Thus, the MMGO method shows promising performance.

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1. INTRODUCTION

Technology development today is speedy and spread [1], [2]. This makes accuracy and efficiency increasingly important in using electronic equipment [3]–[5]. DC motors that have become popular in several electronic equipments are also affected [6], [7]. DC motors are widely used in various industrial household applications that demand a flexible speed range [8], [9]. This is to maintain accurate adaptation or where low-speed torque is required.

Speed control is a concept to keep the speed within the required range. The concept of control can be applied based on automatic and manual [10]. DC motors can be controlled with different controls. [11]–[14]. The conventional proportional-integral (PI) and proportional integral derivative (PID) controls are popular and often applied controls. PID is in the spotlight because it has a low price compared to more complex control systems [15], [16]. In addition, the PID can maintain system output according to the value set within the error limit [17], [18]. PID's downside is its lack of toughness [19]–[21].

Nonlinear modeling problems are often a constraint in a control [22], [23]. One effort to solve nonlinear problems is to do mathematical modeling. This provides support in the use of time and cost efficiency. However, mathematical modeling will not be presented easily. This has prompted several researchers to approach the control system.

In recent years, many studies have been presented on optimization-based control concepts such as the application of the whale optimization algorithm (WOA) [24], Henry gas solubility optimization (HGSO) [25], particle swarm optimization (PSO) [26], coronavirus optimization algorithm (COA) [27], Grey wolf optimization (GWO) [28], Harris hawks optimization (HHO) [29], and evolutionary algorithms (EA) [30].

Although several optimized control studies have been presented, there is still much room to be explored in DC motor control. This article presents a control concept based on a modified mountain gazelle optimizer (MMGO) method in tuning PID parameters in DC motors. This article applies 2 performance measurements of the modified mountain gazelle optimization (MGO) method. The first performance measurement is to compare the benchmark function tests with the comparison method, namely the sine tree seed algorithm (STSA) and the original MGO. The MMGO method was tested for DC motor control using PID in the second experiment. In the second test, a comparison method was used, namely the conventional PID method, STSA-based PID (PID-STSA), original MGO-based PID (PID-MGO) and MMGO-based PID (PID-MMGO). The contribution of this article is the application of PID control on DC motors using the MMGO method.

2. RESEARCH METHOD

2.1. Mountain gazelle optimizer

MGO is an algorithm based on the life of mountain gazelles in nature. Animals originating from the Arabian peninsula have a uniqueness close to the Robinia tree. This animal has a very territorial uniqueness. For that reason, they are very far apart from each other. This animal has three groups: parent-child territory, young male territory, and single male zone. The optimization of the MGO algorithm applies five important keys: non-grouping, stag male groups, maternity groups, male zones, and the migration process in search of food [31].

2.1.1. Male zones

This session describes the struggle for territory or females between mountain gazelles. Each individual has a separate and remote area. The character of the young male is to conquer the area of the female. Meanwhile, the other task is to take care of the area itself. This session can be derived mathematically in (1)-(5):

$$M_z = m_g - |(ri_1 \times YM - ri_2 \times X(t)) \times F| \times cv \quad (1)$$

$$YM = X_{ra} \times [r_1] + M_{pr} \times [r_2], ra = \left\{ \left\lfloor \frac{N}{3} \right\rfloor \dots N \right\} \quad (2)$$

$$F = N_1(D) \times \exp \left(2 - it \times \left(\frac{2}{maxit} \right) \right) \quad (3)$$

$$cv = \begin{cases} (\alpha + 1) + r_3 \\ \alpha \times N_2(D) \\ r_4(D) \\ N_3(D) \times N_4(D)^2 \times \cos((r_2 \times 2) \times N_3(D)) \end{cases} \quad (4)$$

$$\alpha = -1 + it \times \left(\frac{-1}{maxit} \right) \quad (5)$$

where the position of the optimum global breaking is m_g , ri_1 and ri_2 are the random values. cv is a coefficient vector that is random and updated in each iteration. X_{ra} is illustrated as a random value with a range ra . M_{pr} is illustrated as the average value of the search agent. The total of search agents is N . A random value from the basic distribution is $N_1(D)$. it and $maxit$ are the current iteration and maximum iteration. r_3 , and r_4 are random numbers $[0,1]$. N_2 , N_3 and N_4 are random numbers in the natural space and the sizes of the issue.

2.1.2. Maternity groups

In this section, the maternity group holds the key to the life cycle of the mountain gazelles. This session will get a challenging stag. This session can be modeled mathematically in (6):

$$MG = (YM + cv) + (ri_3 \times m_g - ri_4 \times x_{rand}) \times cv \quad (6)$$

Where x_{rand} is the vector position of an agent that is randomly chosen from the all population. ri_3 and ri_4 are the integer and the random values.

2.1.3. Stag male groups

In this session, adult males are encouraged to dominate the territory and females. This power struggle occurs between young males and adult males. Behavior in this session can be formulated in (7)-(8):

$$STG = (X(t) - D) + (ri_5 \times m_g - ri_6 \times MG) \times cv \quad (7)$$

$$D = (|X(t)| + |m_g|) + (2 \times r_6 - 1) \quad (8)$$

Where the ri_5 and ri_6 are integers 1 or 2 that are selected randomly. $X(t)$ and r_6 are the positions of the agent vectors in the current iteration and random value.

2.1.4. Migration process

This session describes this animal as having a good running and jumping character. They always move long distances in search of food. This session is formulated in (9):

$$M = (UB - LB) \times r_7 + LB \quad (9)$$

Where UB and LB are the upper and lower limits.

2.2. DC motor schematic

In this session, the mechanical electrical equations and their combination are used to obtain a linear model of a DC motor. Mathematical models and model concepts are explained. The primary key in control design is the accuracy of the model. This brings time and cost savings as well as efficiency. The concept of building the right model is an important step. The popular DC motor modeling concept is the integration of electrical and mechanical equations, which can be seen in the illustration in Figure 1.

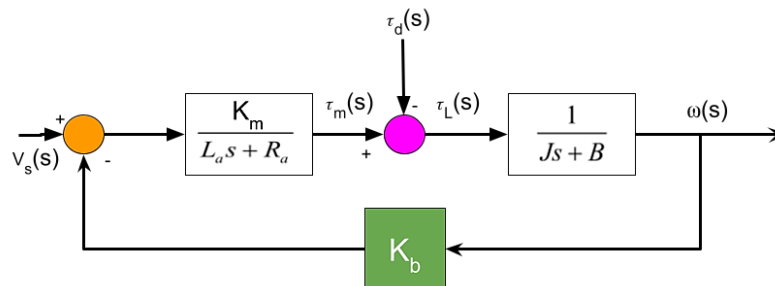


Figure 1. The DC motor schematic [32]

2.3. The modified mountain gazelle optimizer

This article presents a modification of MGO by using the parameters of elite individuals. Individual elites are individuals with minimum fitness.

$$X_{elite} = argmin(f(X_i)) \quad (10)$$

In (10) is integrated into (2) and (5). So that (2) becomes (11) and (5) becomes (12).

$$YM = X_{ra} \times [r_1] + M_{pr} \times [r_2] \times X_{elite}, ra = \left\{ \left[\frac{N}{3} \right] \dots N \right\} \quad (11)$$

$$\alpha = -1 + it \times \left(\frac{-1}{maxit} \right) \times X_{elite} \quad (12)$$

2.4. The proposed MMGO for tuning proportional integral derivative in DC motor

MMGO is used to obtain PID parameters to obtain DC motor adaptive control. This is to get the optimal transient response points. An illustration of the proposed control can be seen in Figure 2.

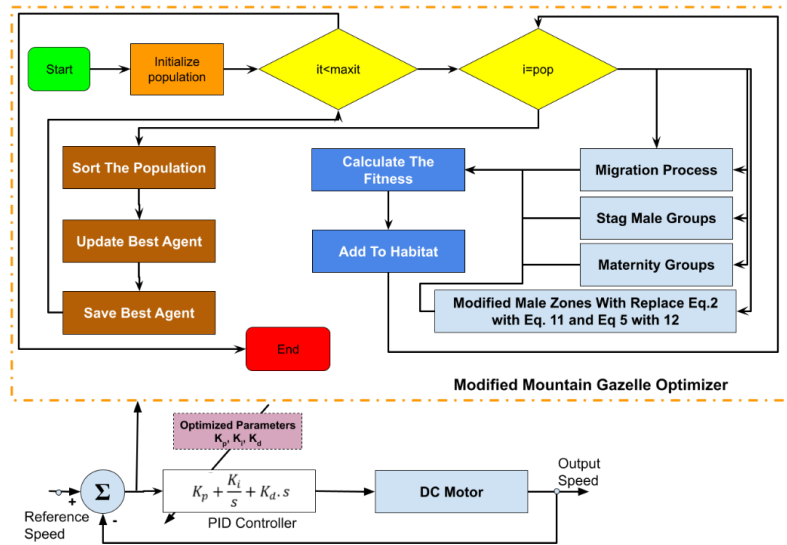


Figure 2. The proposed MMGO methodology

3. RESULTS AND DISCUSSION

MATLAB/Simulink application with a laptop with an Intel I5-5200 2.19 GHz processor specification and 8 GB of RAM are used to perform simulations and write code. The performance measurement of the MMGO algorithm uses the benchmark function. This is to determine the performance of the proposed method. The set of mathematical problems has 23 benchmark functions. This set comprises 10 fixed-dimensional multimodal functions F14–F23, 6 multimodal functions F8–F13, and 7 unimodal functions F1–F7. Figures 3(a) to (g) (in appendix) show the unimodal. Figures 3(h) to (m) (in appendix) show the multi-modal function chart. Figures 3(n) to (v) (in appendix) show the composite function chart. Details of the performance measurement with the benchmark function can be seen in Figure 3.

DC motor control that uses PID requires precise and accurate parameter tuning. The application of MMGO to get good PID parameters is also necessary to validate its performance. The results of the PID control for DC motors by applying MMGO can be seen in Figure 4. Several theories can be used to measure the performance of a control. Some well-known theories include integral square error (ISE), integrated absolute error (IAE), and integral time square error (ITSE). In this article, ITSE is used as performance validation.

$$ITSE = \int_0^{\infty} t \cdot e^2(t) \cdot dt \quad (13)$$

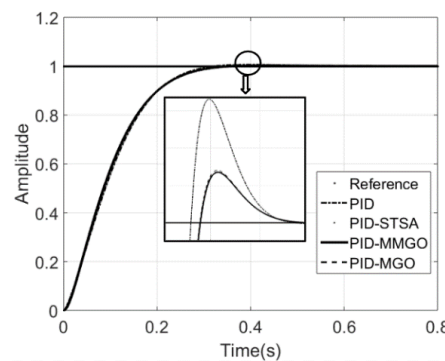


Figure 4. The result of DC motor

By testing the MMGO-based PID on a DC motor with a reference speed of 1 pu, the ITSE of the PID-MMGO is 0.2905. This value is the same as the approach via PID-STSA. The detailed results of the performance test of each algorithm can be seen in Table 1.

Table 1. Output DC motor with PID

Controller	Overshoot	Rise time	Settling time	ITSE
PID-STSA	1.0027	0.1774	0.2841	0.2905
PID-MGO	1.003	0.1777	0.2845	0.2909
PID-MMGO	1.0026	0.1775	0.2841	0.2904

4. CONCLUSION

This article proposes a modified method of the mountain gazelle algorithm. The hierarchy and social structure of wild mountain gazelles served as the inspiration for the development of the MGO. Based on the social and hierarchical requirements of gazelles, the MGO is mathematically modeled. The algorithm is modeled using the fundamental elements, including motherhood herds, bachelor male herds, territorial males, solitude, and migration in quest of food. A solution can conduct the exploratory operation while also progressing toward the ideal solution using the four stages of the proposed model. The proposed method adds a parameter for new exploration and exploitation performance. Performance on DC motor control using a comparison method, namely the conventional PID method, STSA, and the original MGO. From the simulation results, the article finds that the overshoot value of the conventional method can be reduced by 0.447% with the application of MMGO. The ITSE value of MMGO is slightly different from MGO's, which is 0.137%. The application of the MMGO method has promising expectations.

APPENDIX

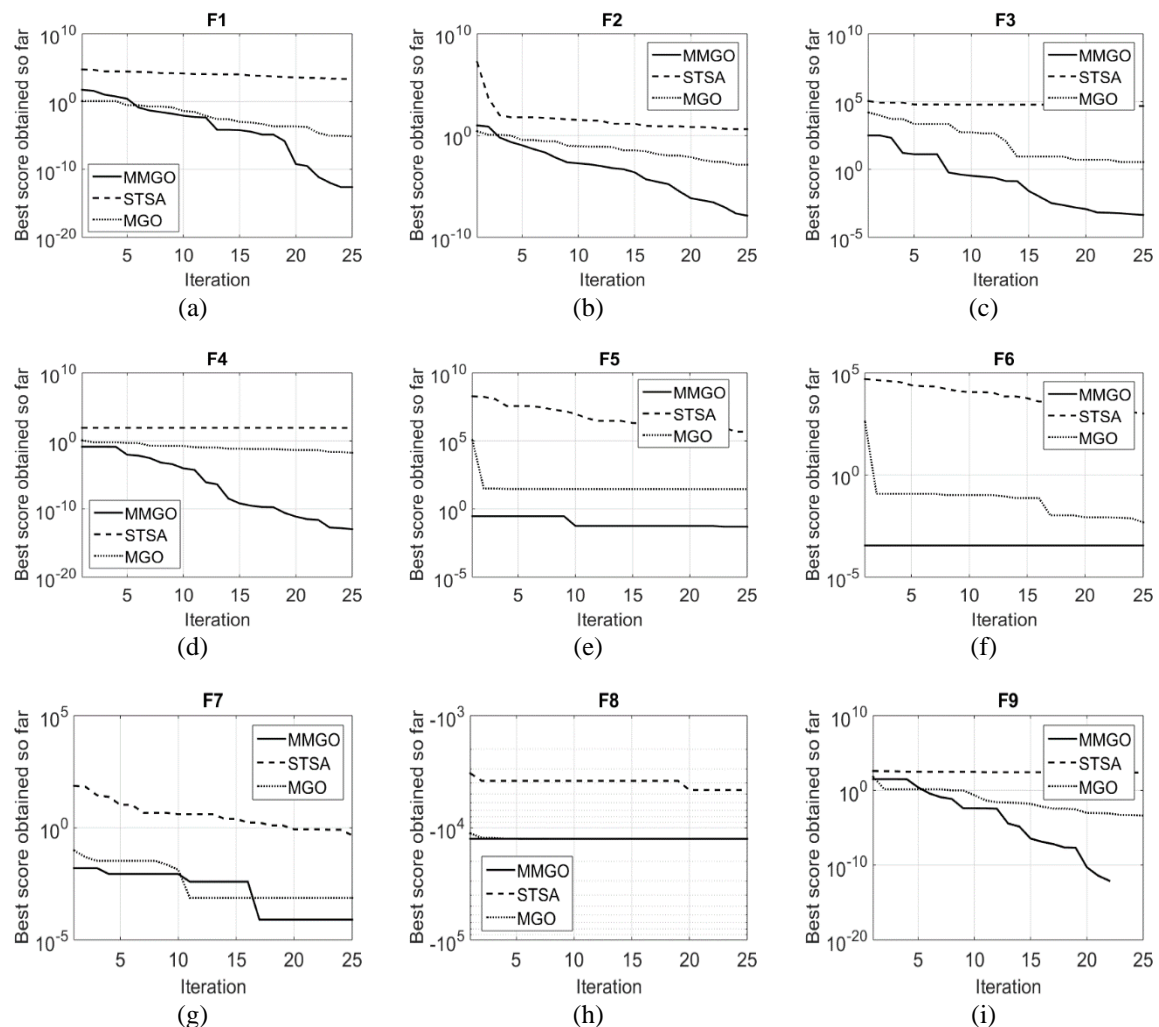


Figure 3. Convergence curve of benchmark function: (a) F1, (b) F2, (c) F3, (d) F4, (e) F5, (f) F6, (g) F7, (h) F8, and (i) F9

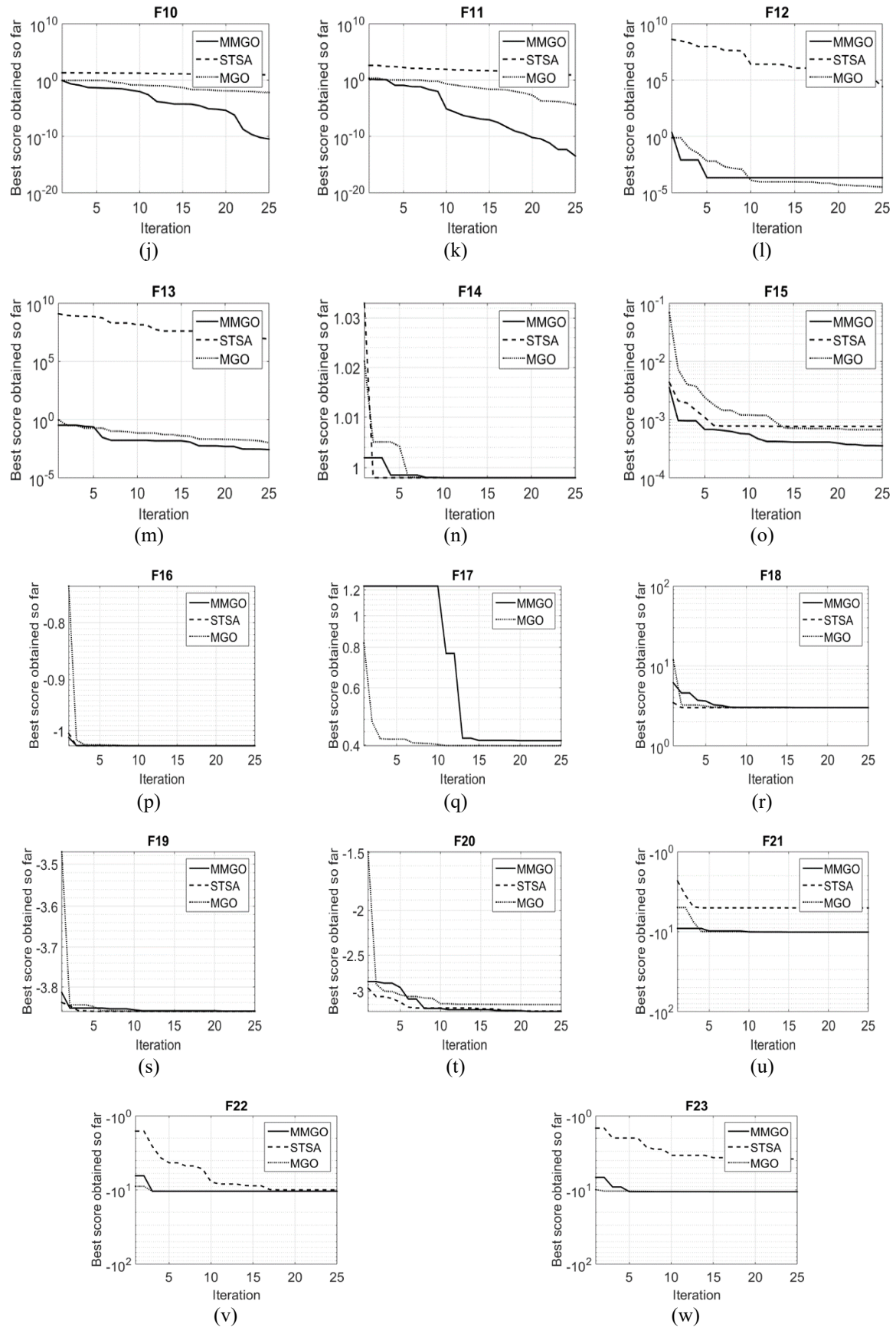


Figure 3. Convergence curve of benchmark function: (j) F10, (k) F11, (l) F12, (m) F13, (n) F14, (o) F15 (p) F16, (q) F17, (r) F18, (s) F19 (t) F20, (u) F21 (v) F22, and (w) F23 (continue)




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